Public Space Public Life 2.0

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Public Space Public Life 2.0: Agent-based Pedestrian Simulation as a Dynamic Visualisation of Social Life in Urban Spaces

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Abstract: This paper investigates the potential of using agent-based modelling (ABM) and artificial intelligence from computer game technology to create an interactive pedestrian simulation as an improved tool for analysing, communicating and visualising the social life of urban spaces in an immersive and dynamic manner. The paper demonstrates that quantitative and qualitative observational data on pedestrians' spatial behaviour derived from ethnographic fieldwork at Torvehallerne in Copenhagen (Denmark) constitutes a set of backbone data to construct agents' spatial behaviour in the simulated environment. The findings of this paper highlight the potential of using ABM and game technology in the realm of landscape architecture and urban design. It also identifies the structure sets of spatial behaviour parameters required for interactive pedestrian simulation, as well as the types of physical settings and their influence on the agent's spatial behaviour.

Keywords: Human-centred urban design, evidence-based design, pedestrian simulation, artificial intelligence, urban life

1 Introduction

Human-centred urban public spaces are defined as accessible, walkable, safe, enjoyable, liveable, and inclusive and allow vibrant social interactions in places where people spend their leisure time, meet friends, and encounter other people (GEHL 2010, MEHTA 2013, MADANIPOUR 2010, CARMONA 2014, ALMAHMOOD et al. 2018). Therefore, understanding the relationship between people and the urban environment they inhabit has been a key factor in the contemporary practice of urban design (GEHL 2010, BOSSELMANN 2008, CARMONA et al. 2010). Architects, urban designers, planners, and urban sociologists have studied and documented human behaviour in urban spaces and have developed and shared evidence-based techniques for spatial and behavioural observation (see, VAN SCHAICK & SPEK 2008, AEL BRECHT 2016, WHYTE 1980, GEHL & SVARRE 2013). Conventional observation techniques include counting people, the visual and semi-automated tracing of movement, mapping behaviour, and tracking individuals and groups. When applied systematically, such techniques can generate evidence-based knowledge about people's spatial behaviour in public spaces or specific information on certain spatiotemporal practices (GEHL & SVARRE 2013). However, these tools are mainly static and provide information about people's present – often retrospect – spatial behaviour as it unfolds, given interaction with the actual physical environment. Quantitative or visual assessments of future situations on the basis of, for instance, proposed urban designs or changes in environmental conditions requires the application of existing

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behavioural knowledge to tools that enable the simulation of interaction between people and the environment, and interaction between individuals or groups.

New, dynamic, smart tools are required to meaningfully connect the observations of people's actual behaviour with simulations of people's potential future use of urban or natural space (SKOV-PETERSEN & GIMBLETT 2008, HONG et al. 2016, KALAY 2004). Such tools can become valuable to designers as they improve the quality of the design process, communicate complex design parameters through a dynamic and immersive approach, and help owners and project stakeholders to make better informed decisions about investments in new or refurbished buildings and open spaces (YAN & KALAY 2005). Further, they allow the effects of potential changes in external conditions, e. g. climate change, increased urban population, transport behaviour, etc. to be addressed.

1.1 Pedestrian Simulation as a Tool in Urban Design

The use of simulations in social science has been gaining popularity since the 1990s as it introduces the possibility of modelling and understanding different social processes (GILBERT & TROITZSCH 2005, GILBERT 2008, TROITZSCH 1997). GILBERT & TROITZSCH (2005) identified the following four aims of simulations in social science: 1) to obtain a better understanding of a certain phenomenon; 2) to predict and look into the future; 3) to substitute for human capabilities, e. g., training models, and; 4) for entertainment purposes, e. g., agent-based video games. The focus of this paper is to investigate the potential role of simulation as a dynamic and interactive architectural representation approach that goes beyond conventional static architectural visualisations, e. g., plan drawings, scheme, and physical models in order to evaluate the potential effects of proposed urban designs on pedestrian movement patterns.

Simulating people's spatial behaviour in a future situation requires the formalisation of observed behaviour to form the basis of a limited number of parameters that can be applied to pedestrian simulation models (GILBERT & TROITZSCH 2005, SKOV-PETERSEN 2005). Agent-based modelling (ABM) is a simulation paradigm that can represent individual pedestrians as autonomous agents who can move and act in the space according to objectives and capabilities, perceived sensory input, existing knowledge, behavioural rules, and the characteristics of the environment (SKOV-PETERSEN & GIMBLETT 2008, BIN & TAO 2011, GILBERT & TROITZSCH 2005). More precisely, in ABM, agents are capable of perceiving, comprehending, and taking action to meet immediate and strategic needs in relation to their surrounding physical and social environments (SKOV-PETERSEN & GIMBLETT 2008). For instance, they can avoid obstacles, follow paths, and avoid other agents as they pursue the goal of their spatial behaviour (GORRINI et al. 2016, SZYMANEZYK et al. 2012). Current pedestrian simulations are spatially and behaviourally limited to some well-defined areas of human activities and spatial domains (YAN & KALAY 2005, HONG et al. 2016). Typically, such simulation models in urban settings focus on the flow of people in space, e. g. pedestrian traffic and emergency simulations, where the aim is to manage the crowd and to improve the physical environment in normal and evacuation situations (see, WAGNER & AGRAWAL 2014, BERNARDINI et al. 2014, PLUCHINO et al. 2013, CHENG et al. 2014). In addition, in many cases, the behavioural and physiological characteristics of agents in the pedestrian simulation models are based on "the average person".

This discussion raises questions regarding the extent to which people's spatial behaviour with its cultural, sociological, and biological differences be parameterised into a computer agent

(Skov-Petersen 2005). Furthermore, to what extent can such technology help us co-create more inclusive and accessible public urban spaces for the benefit of urban life (Jacobs 1961, Gehl 2010, Mehta 2013), which goes beyond simply simulating the spatial behaviour of the "average person" to encompass a diverse set of social groups such as women, children, first-time-visitors, the elderly, and the disabled?

1.2 Study Aim

This paper investigates the potential of agent-based modelling (ABM) and artificial intelligence in computer game technology to create an interactive pedestrian simulation to serve as an improved tool for analysing, communicating and visualising the social life of existing and proposed urban spaces in an immersive and dynamic manner. The paper uses the urban areas around Torvehallerne in Copenhagen, Denmark, as a case for this study (Figure 1).

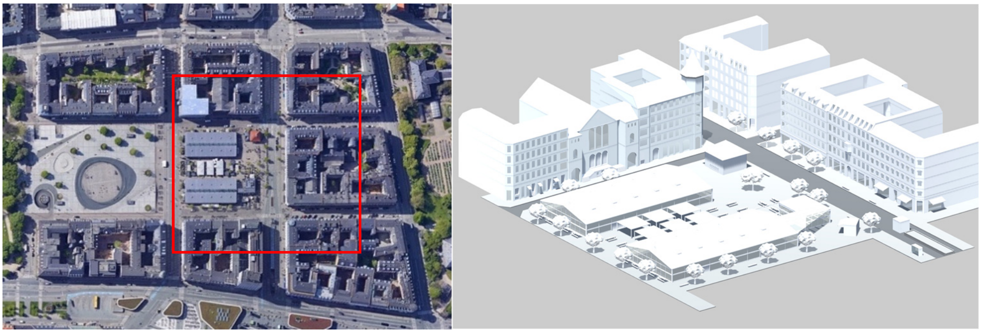

Fig. 1: The aerial view on the left shows Torvehallerne; the study area is indicated by the red square. The 3D model on the right shows the study area in the simulation environment.

2 Modelling Process

This paper discusses the development of a methodological framework that combines qualitative data derived from ethnographic fieldwork with quantitative data from systematic behavioural observations in order to: 1) help define the different types of agent that represent the diverse social groups in a given environment, and; 2) inform agents' spatial and behavioural characteristics, e. g. motivations, spatial knowledge, and abilities (Figure 2). In addition, the modelling framework includes geometric modelling, spatial parameterisation, defined agents, behaviour modelling, and the visualisation of the simulated environment (Figure 2). In this process, instead of the conventional ABM platforms, e. g., NetLogo[1] or GAMA[2], Unity3D[3] was chosen as the game engine to construct our agent-based pedestrian simulation

1 NetLogo is a multi-agent programmable modelling environment. It is used to create agent-based simulations. https://ccl.northwestern.edu/netlogo/.

2 GAMA is a modelling and simulation development environment for building spatially explicit agent-based simulations. https://gama-platform.github.io/.

3 Unity3D is a cross-platform game engine used to create three-dimensional, two-dimensional, virtual reality, and augmented reality games, as well as simulations. https://unity.com/.

model. In contrast to the conventional ABM platforms, Unity3D has high-level graphics and visualisation that integrates VR/AR, an Artificial Intelligence Engine for non-player characters (NPCs), and a well-documented API scripting platform. In addition, Unity3D has been widely used to build simulation platforms recently, as well as architectural visualisations in the realm of urban design, architecture, and industrial design (see, WANG et al. 2018, INDRAPRASTHA & SHINOZAKI 2009, CHRISTIAN & HANSUN 2016, CRISTIE & BERGER 2017, SIMEONE et al. 2016, BUISSON et al. 2013).

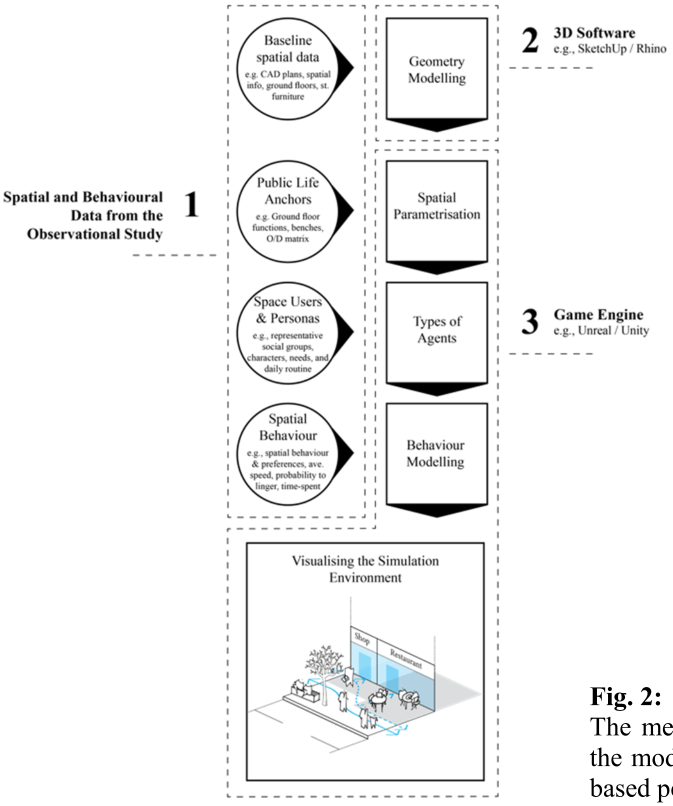

Fig. 2:
The methodological framework for the modelling process of the agent-based pedestrian simulation

2.1 Spatial and Behavioural Data

The spatial behaviour of pedestrians in the study area was analysed and unfolded (Figure 3) through ethnographic fieldwork performed during a weekday between 8am and 8pm by a group of field staff. The fieldwork included survey tasks such as interviews, the counting and tracking of pedestrians, mapping and documenting lingering activities, ground floor analyses, and photographing and taking field notes. The observational data and the detailed findings of the baseline study revealed the number of pedestrians and the types of space user, and they identified the different urban activities performed by the users and visitors to Torvehallerne, Copenhagen.

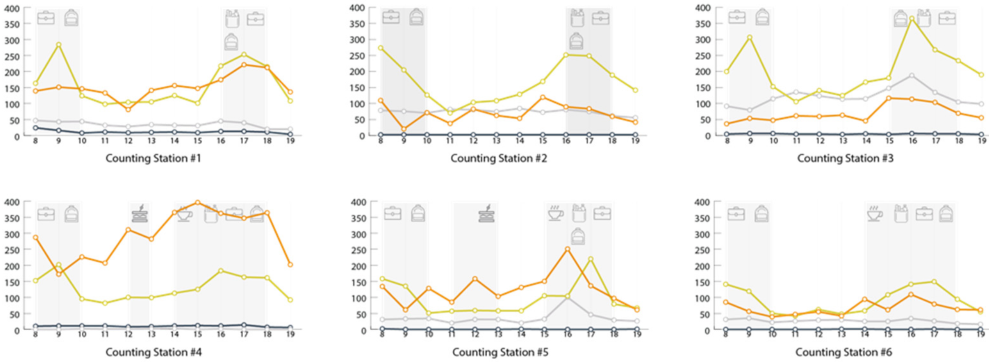

Fig. 3: Pedestrian flows per hour gathered by field staff counting the flow of pedestrians entering the six potential entry points to the study area between 8 AM and 8 PM on the day of the study

In relation to behavioural simulation in public urban spaces, the following four types of spatial and behavioural data constituted the backbone of the agent-based model in this study (Figure 2):

1) Baseline spatial data: information about the physical environment in the form of 2D and 3D GIS- as well as CAD-data. This includes movement network and accessibility (e. g. sidewalks, streets, shared spaces, bike lanes); street furniture (e. g. benches, cafes, playgrounds); ground floor functions (e. g. cafes, restaurants, shops, residential, etc.) as well as inaccessible spaces and buildings.

2) Public life anchors: identifying the spatial parameters that constitute spatiotemporal distribution of pedestrians (agents) in the space. Increasing understanding of the locations where pedestrians enter the study area at different times in relation to the various ground floor functions and street furniture as well as the locations where agents leave the space – known as the origin/destination matrix.

3) Space users and personas: determining which types of user should be included in the simulation model clearly depends on the specific case as well as the nature and focus of the research question. For instance, if the aim is to explore social inclusion in the space, then appropriate types of user might be different ethnic groups and their spatial behaviour and preferences. In the context of this paper, we limited our users to: a) Residents who pass through the study area either as commuters or because they are on an errand – they walk quickly towards their intended destinations taking the shortest path, and; b) Visitors who are mainly tourists – they walk slowly and observe the area looking for potential locations to linger and spend some time in the space. These two types of user represent the main social groups observed during the survey.

4) Spatial behaviour: identifying the behavioural parameters for each type of user including, for instance, average speed, purpose, reaction to others in the space, and spatial preferences. Establishing such a behavioural epistemology is central to the development of the agent-based pedestrian model (Skov-Petersen 2008) and involves the following two classes of information: a) ego-centric information received via the agent's senses,

e. g. the location of objects in space relative to the agent's body, and; b) allocentric information retrieved from exiting sources, e. g. the location of objects in space relative to other objects or agents (MONTELLO 2005, SKOV-PETERSEN & JACOBSEN 2014) (See section 2.3).

2.2 Geometric Modelling and Spatial Parameterisation

The geometric modelling focuses on the urban areas surrounding Torvehallerne including the ground floor environment in order to simulate pedestrians' indoor and outdoor uses. To prepare for spatial parameterisation, in the Sketch-up model, we maintained a layer-based arrangement that consists of each design component of the different surfaces and usage of space. The different spatial components in the 3D model were parameterised based on: 1) walkable, non-walkable, and attractive surfaces for areas such as sidewalks and streets; 2) public anchors – the origins and destinations of the OD matrix representing where agents enter and leave the simulation model; 3) attractive destinations for lingering behaviour, and; 4) obstacles leading to agent's avoidance behaviour (Table 1).

	3D Components / Associated Parameters	Walkable	Non-walkable	Attractive surface	Origin	Destination	Lingering destination	Eating/drinking destination	Obstacle
Surfaces	Sidewalks	•			•	•			
	Squares	•			•	•	•	•	
	Pedestrian crossings	•							
	Indoor spaces	•							
	Water bodies		•						
	Streets	•			•	•			
	Pedestrianised area	•		•	•	•			
3D Objects	Walls								•
	Windows								•
	Tree spaces		•						
	Benches						•	•	
	Street furniture								•
	Outdoor seating						•	•	
	Stairs	•					•		
Public Anchors	Cafes	•					•	•	
	Shops	•					•		
	Residential	•			•	•			
	Offices	•			•	•			
	Metro station	•			•	•			
	Bus stop				•	•			

Table 1: The spatial parameterisation of the different components in the virtual model

2.3 Types of Agent and Behavioural Modelling

The behavioural modelling of agents considers the following three types of agent's behaviour: 1) Purposeful and goal-oriented behaviour – agents performing this behaviour apply knowledge represented as a virtual "cognitive map" (GOLLEDGE 1999); 2) Browsing behaviour – performed by agents who are new to the space with no previous wayfinding knowledge and are entirely dependent on perceived (visual) information, and; 3) Social behaviour – performed by agents that are part of one group, e. g., families, couples, or friends who are walking together towards one or several destinations. This study focuses on creating agents that simulate different spatiotemporal behaviour that was witnessed in the observational studies on the various social groups in the study area.

As described by SKOV-PETERSEN & GIMBLETT (2008), a key element of simulated agents' behaviour is their ability to: 1) perceive the different information in the virtual environment, e. g., the location of the destination; 2) process and comprehend the information provided by the virtual environment in line with agents' needs, e. g., the ability to perceive the spatial qualities of the destination, and accordingly; 3) take action, e. g., take the next step towards their destination (Figure 4). Therefore, in the behavioural modelling, we used Behaviour Tree (BT) as an AI paradigm to develop the behavioural models of agents (MARCOTTE & HAMILTON 2017). BT is a modelling framework for structuring the switching between different tasks and activities in the behavioural modelling of autonomous agents (COLLEDANCHISE & ÖGREN 2017). Each task in the tree is coded separately and structured in the BT to represent a decision or activity to be performed by agents. The combination of these tasks under a BT facilitates the creation of complex spatiotemporal behaviour and parameters. Thus, in the behavioural modelling, we aimed to develop agents' ability to navigate and avoid obstacles, perform lingering activities, as well as adapt instantly to the different physical/temporal settings and qualities of the virtual environment. In addition, the simulation considers the temporal dimension (day/night cycle) and the impact of the sun/shade on the spatial setting of the virtual environment and any influence this may have on agents' perception of spatial quality and, thereby, the likelihood agents will linger in the space.

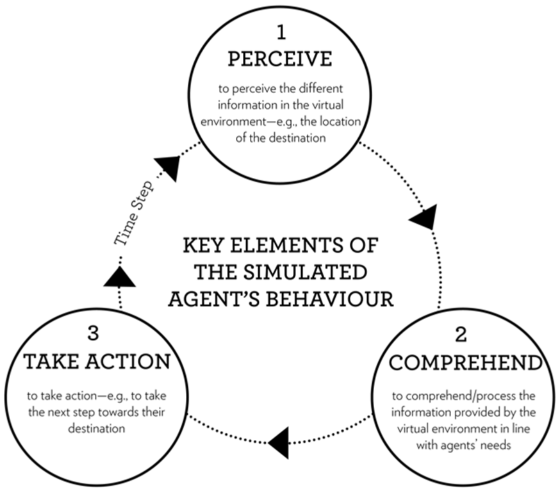

Fig. 4:
The key elements and basic skills of the simulated agent's behaviour

In simulation models, behavioural choices are applied stochastically rather than deterministically, i. e. the actual choice (whether it be the selection of a route, the decision to walk left or right around a lamppost, or to sit down on a bench) is applied as a random draw, weighted by options and preferences. In addition and to avoid the uniform behaviour among the various agents who belong to the same type, our behavioural modelling applies stochastic randomisation to the set of parameters that influence the agent's behaviour in each BT. The randomisation is meant to add a more realistic sense to the behaviour conducted by agents in the simulation. This includes the arrival rate of agents per entry location, the probability of lingering, the duration of the time spent lingering or standing, the speed of movement, as well as their avoidance behaviour.

3 Visualising the Simulated Environment

The visualisation of the simulation model includes a 3D animation that shows the geometry of the virtual environment of Torvehallerne and the surrounding area and the different types of agents using the space (Figure 5). During the run-time of the simulation, agents demonstrate the ability to conduct spatial behaviour that is similar to the behaviour and urban activities witnessed in our observational study, e. g., walking between destinations, lingering in the square and at different locations, as well as avoiding collisions with obstacle objects and other agents. The colour associated with each agent represents the type that the agent belongs to – residents are in red, while visitors are in light blue. The locations where agents enter the simulation environment are also the location of pedestrian-counting stations in the observational study. Once agents enter the virtual environment, their behavioural models begin to allow them to process the different information provided by the virtual environment, e. g., the walkable surfaces, intended destinations, benches, obstacles, cafes and restaurants, etc.

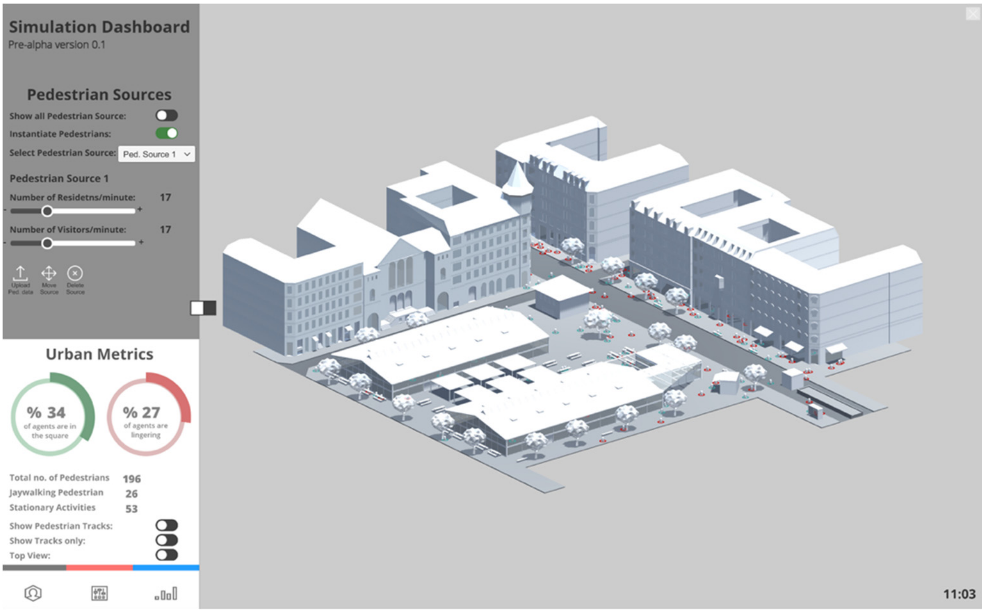

Fig. 5: Screenshot of the virtual environment during the runtime of the simulation. The dashboard on the left shows the Pedestrian Sources 'the origin' points. In the bottom left, the Urban Metrics shows basic real-time readings of the simulation environment, e. g., 34 % of all agents are in the market square and 27 % of all agents are lingering.

In addition, the simulation model also focuses on interaction with the end-user. Thus, it is combined with a use interface dashboard. Figure 5 shows that the simulation environment is divided into two sections; the dashboard area and the virtual urban environment:

5) The main dashboard area consists of several sub-dashboards, where the user can control the parameters that affect and shape the simulation environment. For instance, the Pedestrian Source allows users to specify the locations where agents enter the physical environment as well as control the pedestrian volume by assigning the number of pedestrians per minute for each entry point. In addition, real-time urban metrics are embedded, which allows numerical readings of the simulation environment to be taken, e. g., the number of agents performing lingering activities, the percentage of agents who are located on the market square. It also enables the generation of tracks of pedestrian movement and points of lingering activities that increase understanding of the different use patterns of the space (Figure 6).

The physical environment area consists of a 3D model of the examined area. Users can upload their 3D models directly to the simulation environment via this standalone simulation app. They can also zoom, pan, rotate, and orbit around the 3D model during the runtime of the simulation. This helps the user to visualise the interactions between the agents and the physical setting from multiple views and at different scales.

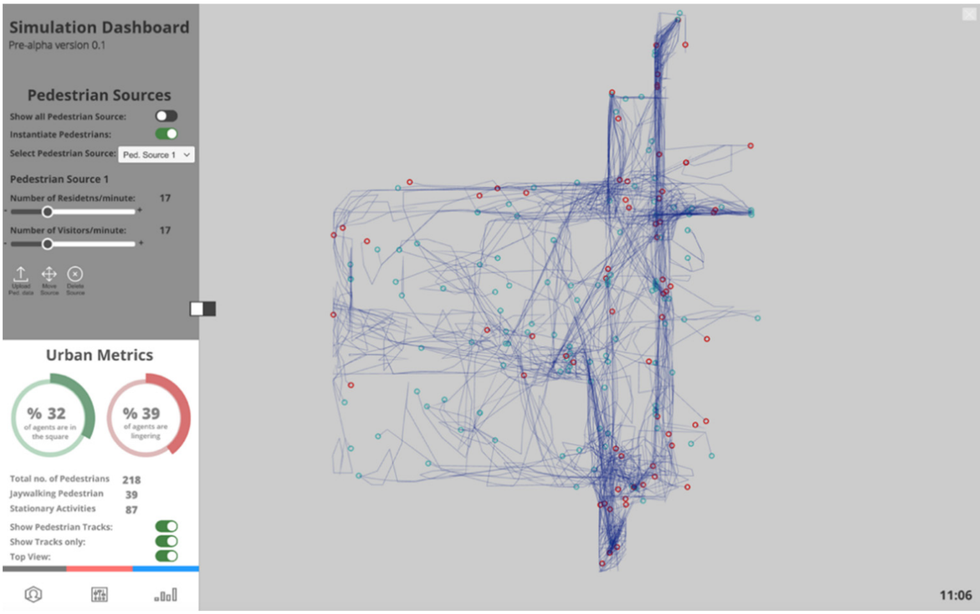

Fig. 6: The use of urban metrics to generate agents' movement patterns – viewed from above

4 Discussion

Our study generates valuable knowledge about the potential of agent-based modelling and artificial intelligence in games technology to create dynamic, interactive agent-based pedestrian simulation environments. It also highlights the potential avenues in which the simulation modelling approach may serve as a better communication tool in terms of architectural representation. However, we acknowledge the trade-offs, limitations, and shortcomings. As GILBERT & TROITZSCH (2005) have argued, any simulation model is inherently a reduced version of the observed social phenomenon and, accordingly, it is important to highlight and communicate the reductions applied:

- The lack of social interaction – agents in this simulation model are autonomous entities. They do not interact with each other as pedestrians may do in real life. Therefore, the 'spontaneous' interaction that may occur between agents has yet to be developed.
- Temporal limitations – this simulation model relies on a dataset taken from one day in the year. Thus, it is not based on a holistic dataset that is informed by different times of the day and week, and it does not take seasonal changes into account.
- Microclimatic influence – in the model, the influence of the weather is limited to the sun and shade and, therefore, the potential influence of the wind, rain, and temperature on agents' behaviour is not taken into consideration.

5 Conclusion and Outlook

The paper discusses a methodological framework that integrates quantitative and qualitative observational data on pedestrians' spatial behaviour derived from ethnographic fieldwork at Torvehallerne in Copenhagen, Denmark, to construct agents' spatial behaviour in a simulated environment. The following three types of agents' behaviour were considered in the simulated environment; 1) purposeful and goal-oriented behaviour; 2) browsing behaviour, and; 3) social behaviour, which is limited to the groups who move together towards one destination, e. g. couples and families. Therefore, the project contributes to the literature by exploring the link between observed and simulated individual behaviour and the aggregated measures of pedestrians' use of public spaces to communicate and mediate urban design processes. The findings of this project highlight the potential of using ABM and games technology in the realm of landscape architecture and urban design. Using games technology helps to construct real-time interactive, immersive, and highly visual agent-based pedestrian simulations. Hence, beyond the conventional static architectural visualisation, using a game engine to create an agent-based pedestrian simulation paves the way for exploring the potential role of the simulation as a dynamic and interactive representation of social life in urban spaces.

Ultimately, simulating social phenomena, e. g. pedestrians' urban activities in public space is a very complex process as it involves many multi-dimensional layers and causal mechanisms that constitute spatial behaviour in the built environment. However, this complexity may lead to numerous research opportunities, especially and the identification of areas where the simulation may be a useful tool for the creative design process. Future studies should also explore the uses of pedestrian simulations in architecture education. Hence, the paper highlights and paves the way for future research that:

- Identifies the types of socio-spatial parameter that may also influence the way agents experience the use of public spaces.
- Explores the different ways of using such immersive and interactive simulation environments in the public engagement and participatory planning process.
- Assesses and tests the potential effects and the effectiveness of applying ABMs in the context of a live urban design project with different stakeholders.

- Develops methods for generating, communicating, and visualising aggregated measures of agents' behaviour, for instance, heatmaps of moving and stationary agents, and temporal profiles of the level of satisfaction of agents, etc.

Acknowledgement

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